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A PARAMETRIC INVESTIGATION OF RIDE QUALITY RATING SCALES

By

Thomas K. Dempsey, Glynn D. Coates, and

Jack D. Leatherwood

September 1976

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16. Abstract

An experimental investigation was conducted to determine (1) the relative merits of various category scales for the prediction of human discomfort response to vibration and (2) the mathematical relationships that allow for transformations of subjective data from any one scale to any other scale. A total of 16 category scales were studied and these represented various parametric combinations of polarity (i.e., unipolar and bipolar), scale type (continuous or discrete), and number of scalar points (3, 5, 7, or 9). Sixteen subject groups (12 subjects per group) were used and each subject group evaluated their comfort/discomfort to vertical sinusoidal vibration using one of the rating scales. The experimental apparatus utilized was the Langley Research Center's Passenger Ride Quality Apparatus which can expose six subjects simultaneously to predetermined vibrations. For this study, the vibration stimuli were composed of repeats of selected sinusoidal frequencies (1, 2, 4, 5, 8, 10, 15, and 20 Hz) applied at each of nine peak floor acceleration levels (0.05, 0.075, 0.10, 0.125, 0.15, 0.175, 0.20, 0.225, and 0.25 g).

Results indicated that a higher degree of reliability and discriminability were generally obtained from unipolar, continuous type scales containing either seven or nine scalar points as opposed to the other scales investigated. Furthermore, transformations of subjective data between category scales was found to be possible with the unipolar scales with the larger numbers of scalar points giving the greatest accuracy of transformation. A result of particular interest was that the comfort (or positive) half of a bipolar scale was seldom used by subjects to describe their subjective reaction to vibration.

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ABSTRACT

An experimental investigation was conducted to determine (1) the relative merits of various category scales for the prediction of human discomfort response to vibration and (2) the mathematical relationships that allow for transformations of subjective data from any one scale to any other scale. A total of 16 category scales were studied and these represented various parametric combinations of polarity (i.e., unipolar and bipolar), scale type (continuous or discrete), and number of scalar points (3, 5, 7, or 9). Sixteen subject groups (12 subjects per group) were used and each subject group evaluated their comfort/discomfort to vertical sinusoidal vibration using one of the rating scales. The experimental apparatus utilized was the Langley Research Center's Passenger Ride Quality Apparatus which can expose six subjects simultaneously to predetermined vibrations. For this study, the vibration stimuli were composed of repeats of selected sinusoidal frequencies (1, 2, 4, 5, 8, 10, 15, and 20 Hz) applied at each of nine peak floor acceleration levels (0.05, 0.075, 0.10, 0.125, 0.15, 0.175, 0.20, 0.225, and 0.25 g).

Results indicated that a higher degree of reliability and discriminability were generally obtained from unipolar, continuous type scales containing either seven or nine scalar points as opposed to the other scales investigated. Furthermore, transformations of subjective data between category scales was found to be possible with the unipolar scales with the larger numbers of scalar points giving the greatest accuracy of transformation. A result of particular interest was that the comfort (or positive) half of a bipolar scale was seldom used by subjects to describe their subjective reaction to vibration.

*Old Dominion University

INTRODUCTION

The ride quality literature over the past 50 years has emphasized the importance of passenger reactions to vibration in the development of comfort criteria for use in vehicle design. A recent review (ref. 1) of the criteria literature points out that many differences and contradictions exist in the various reported investigations and that one possible contributing factor to these large differences could be the use of inappropriate scaling techniques. Invariably, during formal (e.g., refs. 2 and 3) or informal ride quality meetings, rating scales are discussed and viewed as a major (if not the greatest) cause of this criteria variability. The purpose of this study is to determine the relative merits of various rating scales, and to determine the mathematical relationship that will allow transformation of subjective data between various scales.

The large number of rating scales that have been used and discussed can be characterized according to (1) the adjectives or adverbs that are used for anchoring scalar points, (2) polarity; whether or not a passenger is allowed to evaluate his ride sensation in a unipolar or bipolar fashion, (3) scale type; either the category scale is of a line variety and continuous in nature, or consists of category boxes of a discrete nature, and (4) the number of scalar points or category demarcations provided on the scale. Many discussions among ride quality investigators have centered upon the question of which of these scales is the "most appropriate" for use in the development of ride quality criteria. Answers to these questions could be determined from experimental tests of (1) reliability; the determination of which

scale allows subjects to display the greatest repeatability in subjective evaluations, (2) discriminability; an assessment of which subjective scale allows the subjects to provide maximum discrimination between vibration spectrum characteristics, and (3) flexibility of the scale in allowing transformation of the subjective responses to other scales reducing what is merely an apparent variability between comfort criteria.

The investigation of different adjective anchors is not considered in the present paper since it would present an almost endless search for the "most appropriate" subjective scale. Consequently, the present study selected as an anchor for all scale variations the adjective "comfort-discomfort" which is probably the simplest and most frequently occurring adjective used in this type of study.

The purpose of the present study is, therefore, to conduct a parametric investigation of scale polarity, scale type, and scalar points. These different scales are to be evaluated in terms of the previously mentioned factors of scale appropriateness, namely, reliability, discriminability, and the ease or flexibility governing transformation of subjective data from one scale to another.

METHOD

Simulator

The apparatus used was the Langley Passenger Ride Quality Apparatus (PRQA). The PRQA is described briefly in this section and a detailed description can be obtained from references 4 and 5. The PRQA and associated programing and control instrumentation are shown in the photographs of figure 1 on the next page. Figure 1(a) shows the waiting room where subjects are instructed as to their participation in the experiment, complete questionnaires, etc. Figures 1(b) and 1(c) are photographs of the exterior of PRQA, and it should be noted that the actual mechanisms which drive the simulator are located beneath the pictured floor. Shown in figure 1(d) is a model of the PRQA indicating the supports, actuators, and restraints of the three-axis drive system. The control console is shown in figure 1(e) and is located at the same level as the simulator to allow the console control operator to constantly monitor subjects within the simulator. An interior view of PRQA fitted with tourist-class aircraft seats is shown in figure 1(f). Additional interior views (with front or back panels removed) of PRQA are displayed in figures 1(g), 1(h), and 1(i). To reduce the influence of extraneous noises produced by the equipment, music was played in the PRQA. In addition, each subject was requested to use ear plugs (see ref. 6).

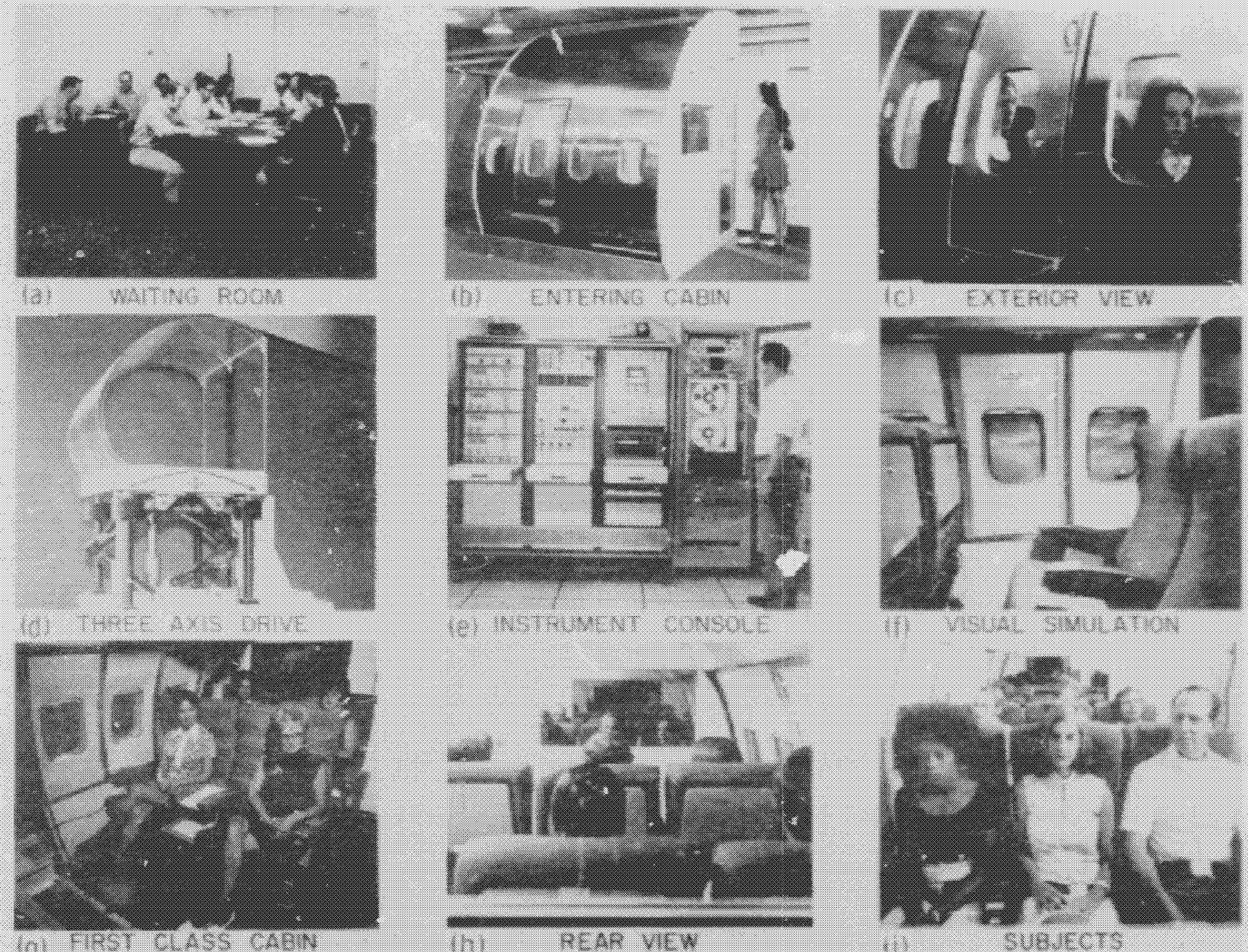
(a) WAITING ROOM
(b) ENTERING CABIN
(c) EXTERIOR VIEW
(d) THREE AXIS DRIVE
(e) INSTRUMENT CONSOLE
(f) VISUAL SIMULATION
(g) FIRST CLASS CABIN
(h) REAR VIEW
(i) SUBJECTS

Figure 1

Subjects

A total of 192 subjects participated in the study. The volunteer subjects were obtained from Old Dominion University (undergraduate students) and from a contractual subject pool, and were paid for their participation in the study. The ages and weights of the subjects are listed in the following table.

TABLE I.- SUBJECT DEMOGRAPHICS

Subject		Age		Weight	
Sex	Number	Median	Range	Mean	Standard Deviation
Males	61	21	18-46	165.98	21.88
Females	131	21	18-55	129.05	24.31
Total	192	21	18-55	140.78	29.15

Subjective Evaluation Scales

A total of 16 different scales were investigated in the present study. These scales were parametric combinations of polarity (unipolar or bipolar), scale type (continuous or discrete), and number of scalar points (3, 5, 7, or 9 points). The exact scales are displayed below in figures 2(a-p).

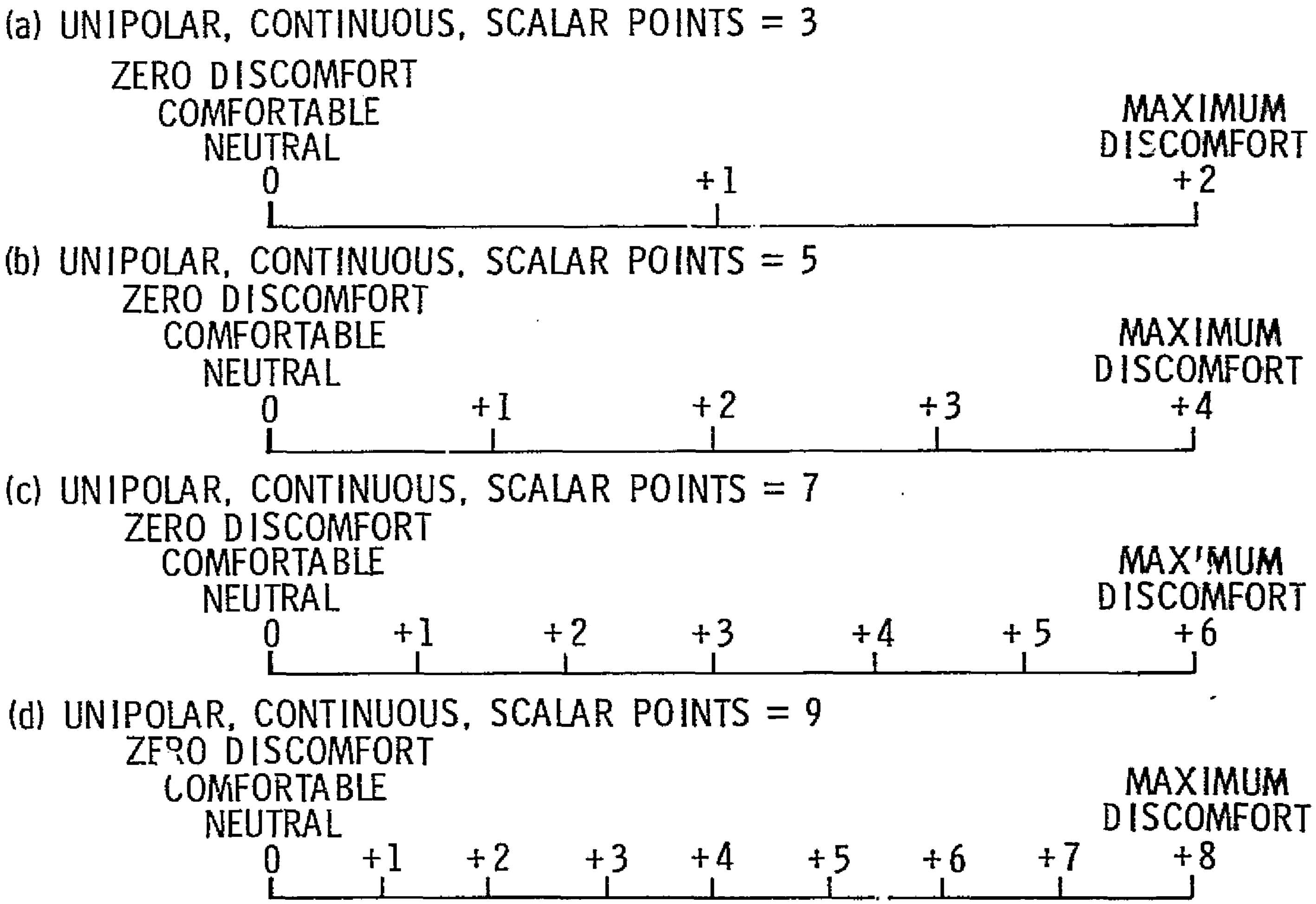
(a) UNIPOLAR, CONTINUOUS, SCALAR POINTS = 3
ZERO DISCOMFORT
COMFORTABLE
NEUTRAL
MAXIMUM
DISCOMFORT
0
+1
+2
(b) UNIPOLAR, CONTINUOUS, SCALAR POINTS = 5
ZERO DISCOMFORT
COMFORTABLE
NEUTRAL
MAXIMUM
DISCOMFORT
0
+1
+2
+3
+4
(c) UNIPOLAR, CONTINUOUS, SCALAR POINTS = 7
ZERO DISCOMFORT
COMFORTABLE
NEUTRAL
MAXIMUM
DISCOMFORT
0
+1
+2
+3
+4
+5
+6
(d) UNIPOLAR, CONTINUOUS, SCALAR POINTS = 9
ZERO DISCOMFORT
COMFORTABLE
NEUTRAL
MAXIMUM
DISCOMFORT
0
+1
+2
+3
+4
+5
+6
+7
+8

Figure 2

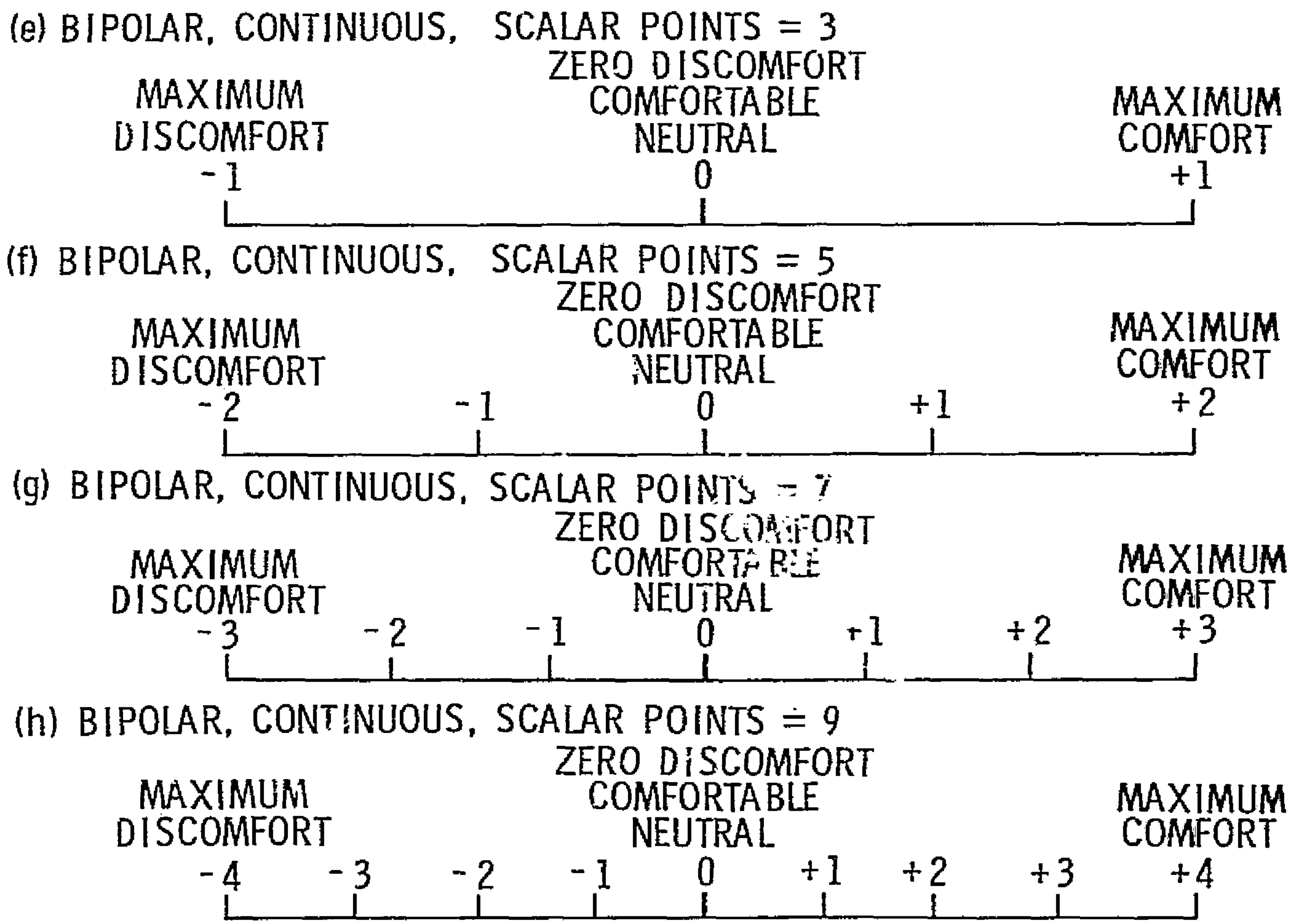

Figure 2 (Continued)

(i) UNIPOLAR, DISCRETE, SCALAR POINTS = 3

ZERO DISCOMFORT COMFORTABLE NEUTRAL		MAXIMUM DISCOMFORT
0	+1	+2
☐	☐	☐

(j) UNIPOLAR, DISCRETE, SCALAR POINTS = 5

ZERO DISCOMFORT COMFORTABLE NEUTRAL				MAXIMUM DISCOMFORT
0	+1	+2	+3	+4
☐	☐	☐	☐	☐

(k) UNIPOLAR, DISCRETE, SCALAR POINTS = 7

ZERO DISCOMFORT COMFORTABLE NEUTRAL						MAXIMUM DISCOMFORT
0	+1	+2	+3	+4	+5	+6
☐	☐	☐	☐	☐	☐	☐

(l) UNIPOLAR, DISCRETE, SCALAR POINTS = 9

ZERO DISCOMFORT COMFORTABLE NEUTRAL								MAXIMUM DISCOMFORT
0	+1	+2	+3	+4	+5	+6	+7	+8
☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 2 (Continued)

(m) BIPOLAR, DISCRETE, SCALAR POINTS = 3

MAXIMUM DISCOMFORT	ZERO DISCOMFORT COMFORTABLE NEUTRAL	MAXIMUM COMFORT
-1	0	+1
☐	☐	☐

(n) BIPOLAR, DISCRETE, SCALAR POINTS = 5

MAXIMUM DISCOMFORT		ZERO DISCOMFORT COMFORTABLE NEUTRAL		MAXIMUM COMFORT
-2	-1	0	+1	+2
☐	☐	☐	☐	☐

(o) BIPOLAR, DISCRETE, SCALAR POINTS = 7

MAXIMUM DISCOMFORT			ZERO DISCOMFORT COMFORTABLE NEUTRAL			MAXIMUM COMFORT
-3	-2	-1	0	+1	+2	+3
☐	☐	☐	☐	☐	☐	☐

(p) BIPOLAR, DISCRETE, SCALAR POINTS = 9

MAXIMUM DISCOMFORT				ZERO DISCOMFORT COMFORTABLE NEUTRAL				MAXIMUM COMFORT
-4	-3	-2	-1	0	+1	+2	+3	+4
☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 2 (Concluded)

Subject Instruction

The subjects were instructed to base evaluations upon the comfort (or discomfort) of a vibration. Prior to the start of testing for each session, the subjects were exposed to a vibration (4 Hz, 0.25 peak g) and told the vibration usually resulted in a rating of maximum discomfort. The subjects were purposely not given a vibration typical of maximum comfort since such a vibration is difficult to specify and would in fact bias results related to polarity.

Procedure

Sixteen groups of subjects (composed of 12 subjects per group) each used one of the previously mentioned category scales to evaluate successive "ride segments." A ride segment, as displayed in Table II was a single vertical frequency (1, 2, 4, 5, 8, 10, 15, and 20 Hz) at one of nine peak floor acceleration levels (0.05, 0.075, 0.10, 0.125, 0.15, 0.175, 0.20, 0.225, and 0.25g). The factorial combination of these frequencies and acceleration levels resulted in a total of 72 separate ride segments each of which was presented to a subject twice (in order to determine estimates of reliability) for a total of 144 ride segments. The eight frequencies were randomized without replacement (twice) and were used to define the frequency of vibration of a session. The nine peak floor acceleration levels were randomized and determined the nine ride segments of a session. Through the use of a two-way auditory communication system, the subjects were instructed when to begin evaluation of a ride by the word "start" and when to end the evaluation by the word "stop." The onset and offset of a vibration each lasted 5 seconds, the duration of the vibration was 10 seconds, and the interstimulus interval 5 seconds. The subjects were further instructed to ignore rise (onset) and decay (offset) vibrations that occurred prior and subsequent to the words "start" and "stop," respectively.

Each session lasted approximately 5 minutes, with a 1 minute rest period after each session. A 15 minute rest interval was provided after the eighth session instead of the 1 minute interval.

TABLE II.- EXPERIMENTAL DESIGN

Peak g, units	Frequency 1	2	4	5	8	10	15	20
0.050								
0.075								
0.100								
0.125								
0.150								
0.175								
0.200								
0.225								
0.250								

RESULTS AND DISCUSSION

This section provides results and discussion in terms of the factors previously described for determining scale appropriateness; namely, reliability, discriminability, and flexibility of response transformation. Within each of these sections the scale characteristics of polarity, scale type, and number of scalar points are addressed.

Scale Reliability

The extent to which a category scale allows a subject to repeat evaluations to similar vibrations would certainly be an initial requirement of scale appropriateness. Relative to this requirement, the reliability of scales varing in polarity, scale type, and scalar points are discussed in successive sections.

Polarity.- Figure 3 on the following page displays the test-retest reliability correlation coefficients for unipolar and bipolar scales. These correlations include the paired data for different frequencies, acceleration levels, scale type, scalar points, and subjects (N = 6,912 pairs). A z-score (z-score transformation test) of 2.882 indicated there was a statistically ($P < .05$) higher degree of reliability obtained through the use of unipolar than bipolar scales.

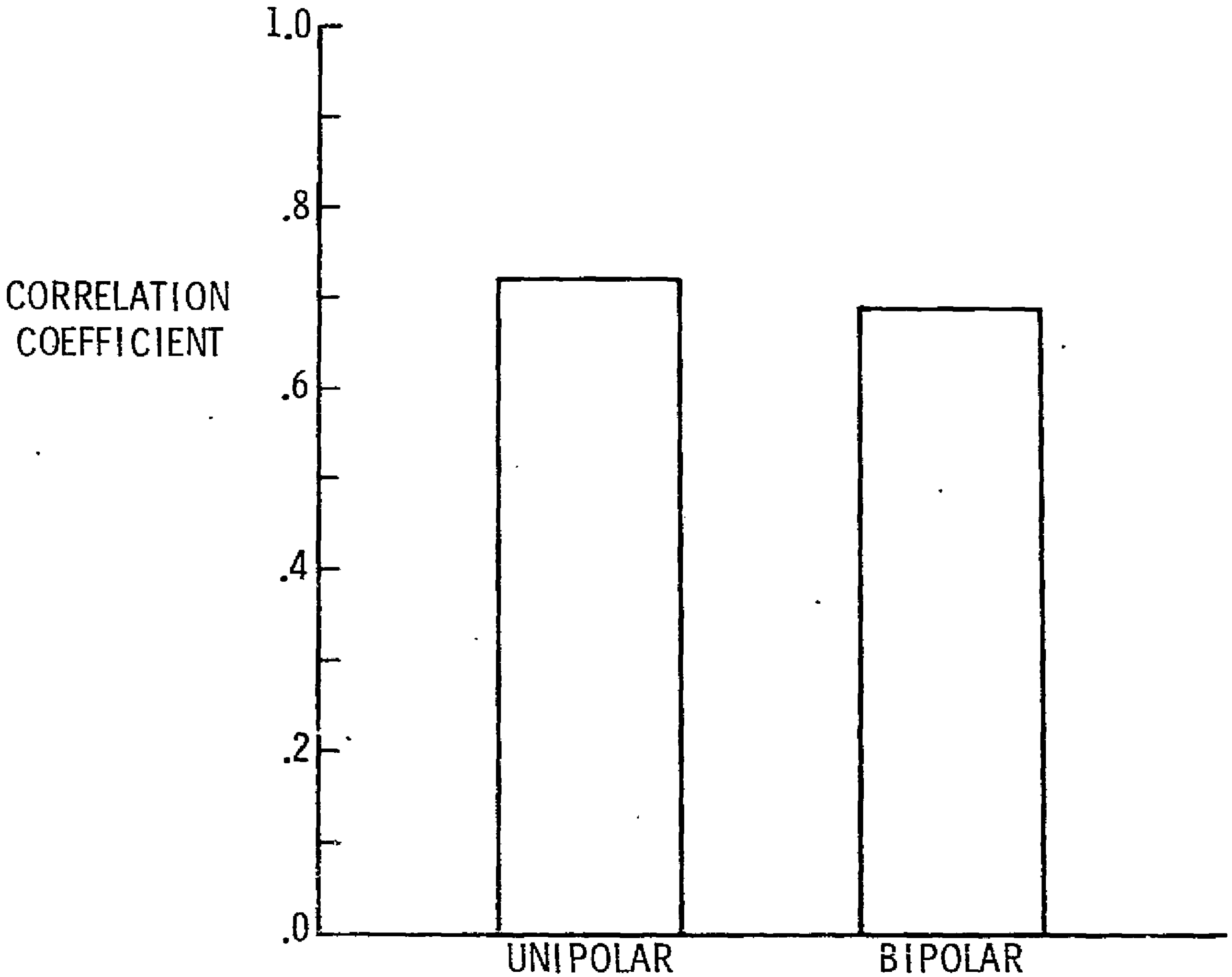

Figure 3

Scale type.- Figure 4 displays the test-retest correlation coefficients obtained for discrete and continuous type scales. In this case, each correlation was based on paired data for different frequencies, acceleration levels, polarity, scalar points, and subjects (N = 6,912 pairs). A z-score of 6.412 indicated there was a statistical difference ($P<.05$) between these two correlations. The results indicate that a significantly higher degree of reliability will be obtained for continuous rather than discrete type scales.

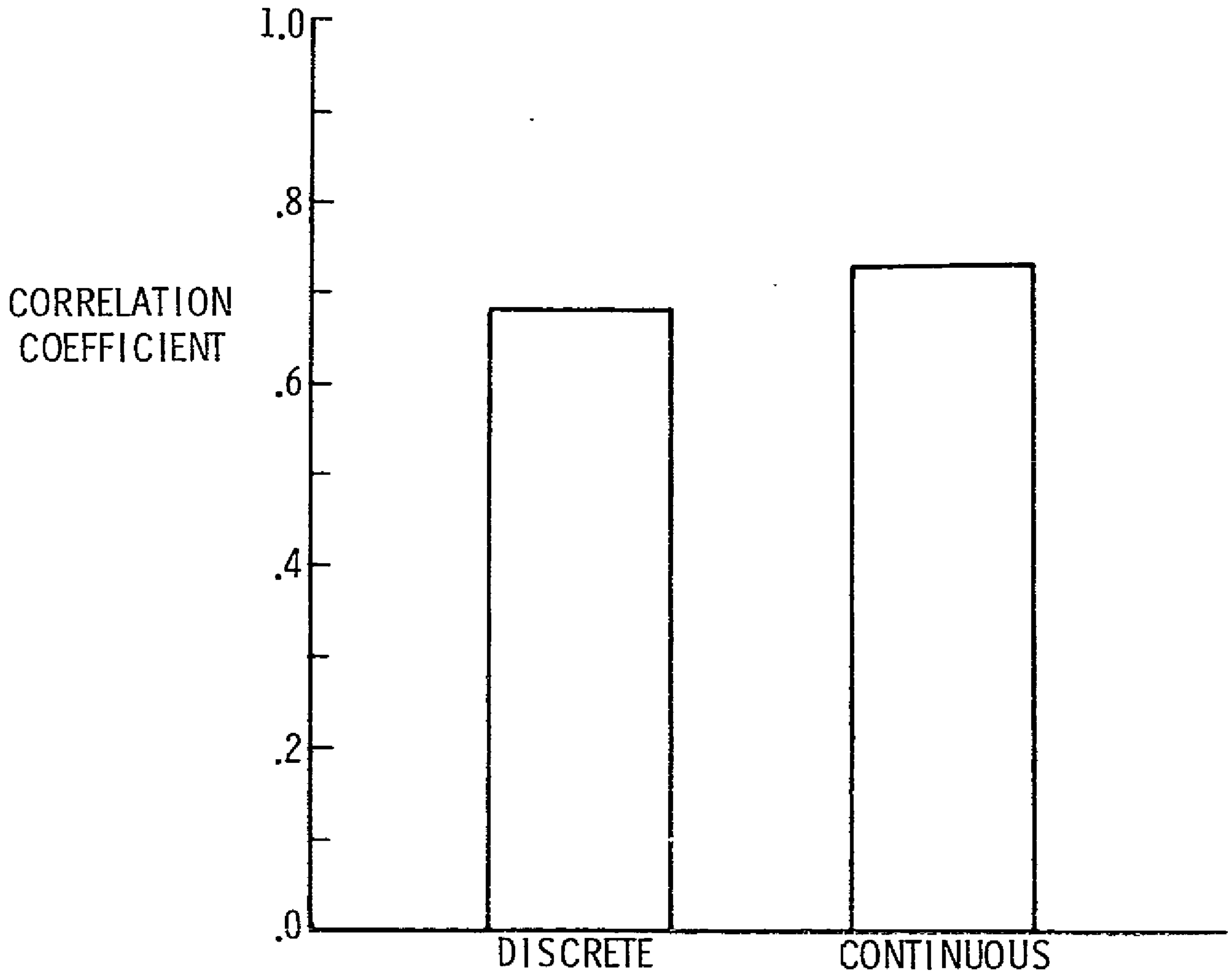

Figure 4

Scalar points.- Figure 5 displays the test-retest correlation coefficients obtained for 3, 5, 7, or 9 scalar points. In this case, each correlation was based on paired data for different frequencies, acceleration level, polarity, scale type, and subjects (N - 3,456 pairs). A series of z-score tests between these correlation coefficients indicated that there was no difference between 3 or 5 scalar points, or between 7 and 9 scalar points. However, there was a statistically higher degree of reliability obtained for 7 and 9 scalar points in comparison to 3 or 5 scalar points (z-scores = 0.7469, 5.3527, 6.2656, 6.0996, 7.0124, and 0.9129 for scalar point comparisons of 3 vs. 5, 3 vs. 7, 3 vs. 9, 5 vs. 7, 5 vs. 9, and 7 vs. 9, respectively.)

Reliability summary.- The results from this series of analyses indicate that higher degrees of reliability will be obtained from certain category scales for evaluation of vibration than other scales. The scales that display the greater reliability are of a unipolar, continuous nature with 7 or 9 scalar points.

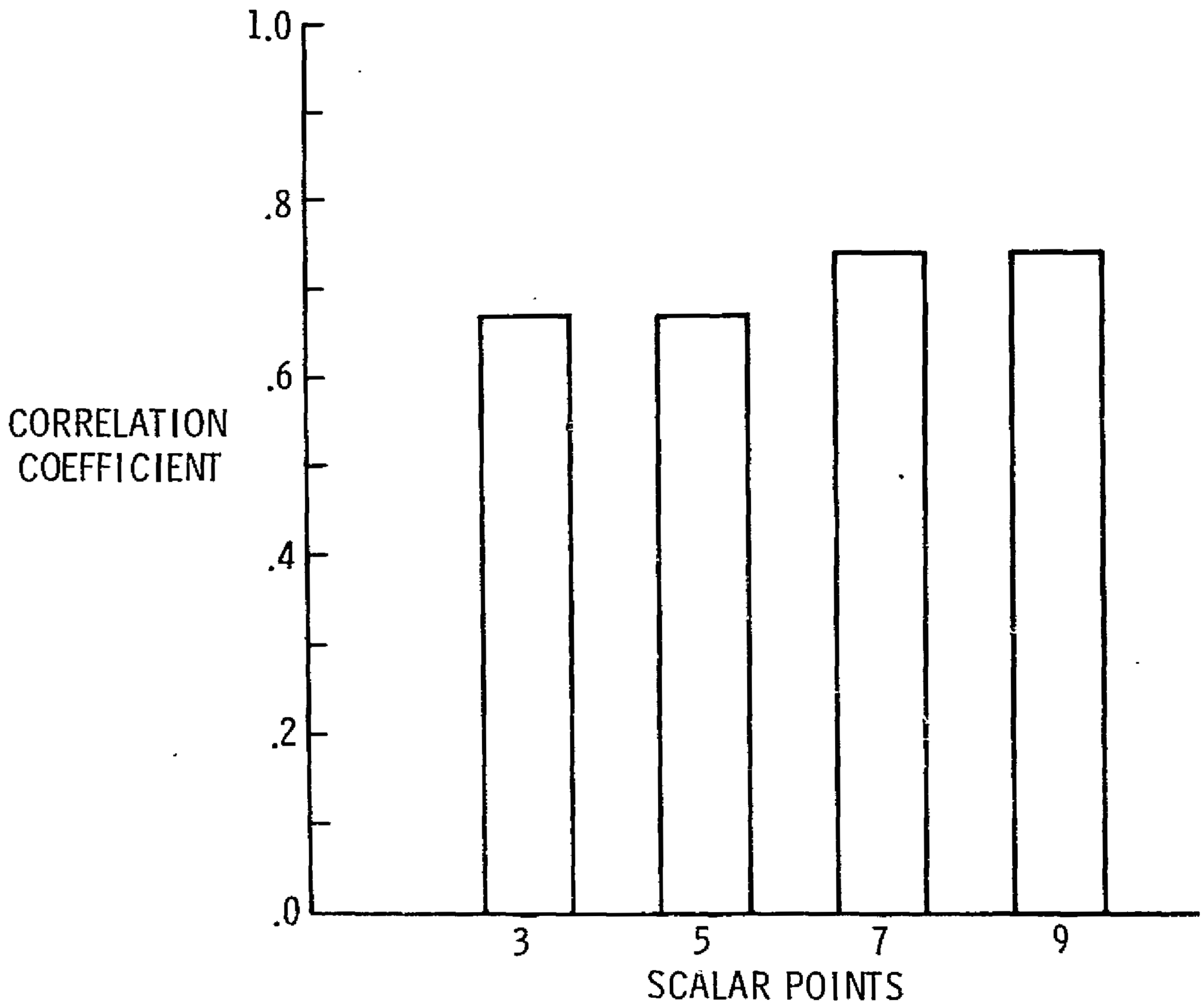

Figure 5

Scale Discriminability

This section addresses the problem of which category scale in terms of polarity, scale type, or number of scalar points allows subjects to provide maximum discrimination between ride spectrum characteristics. However, there are a variety of mathematical relationships that could exist between the category subjective responses and a particular physical measure for the description of discrimination accuracy. The four mathematical relationships (psychophysical formulations) typically discovered are displayed in Table III, where x is the peak acceleration level and a and b are coefficients determined from appropriate least-square fitting techniques. Therefore, the accuracy of discrimination associated with variations of polarity, scale type, and number of scalar points will be determined for each of the mathematical formulations.

TABLE III.- PSYCHOPHYSICAL RELATIONSHIPS

(1) Power ratings = ax^{b}

(2) Logarithmic ratings = $a + b\log x$

(3) Exponential ratings = $a10^{bx}$

(4) Linear ratings = $a + bx$

Polarity.- Figure 6(a-d) displays the correlation coefficients between subjective responses and vibration measures for both unipolar and bipolar scales, for each of the previously mentioned mathematical formulations. The data for each correlation was based on paired data (subjective responses and vibration measures) for different frequencies, acceleration levels, repeats of both frequencies and acceleration levels, scale type, scalar points, and subjects (N = 13,824). However, despite the fact that the correlations were based on twice the number of data pairs as were certain estimates of reliability, the number of pairs used for computation of z-score tests was 144. This number was selected so as not to artificially inflate the degrees of freedom. The z-score tests indicated that there was no statistical difference between unipolar or bipolar scales for any of the mathematical formulations (z-scores = 1.327, 0.957, 1.327, and 1.066 for the linear, logarithmic, exponential, and power comparison of scale polarity, respectively). There is a systematic trend of unipolar scales offering a greater accuracy of discrimination between vibration measures than bipolar scales. In fact, the z-scores indicate that by chance such differences between correlation coefficients would occur only 10 to 15 percent of the time.

Additional z-score tests were computed between the responses of different mathematical descriptions of the same type of scale. For example, it was problematical whether or not there was any difference between a linear or logarithmic description of the relationship between responses and vibration measure for a unipolar scale, etc. There were no statistical differences obtained between any mathematical formulations of these relationships for either scale. The implication of these results being that the simpler linear relationship can be selected for description of the mathematical relationship.

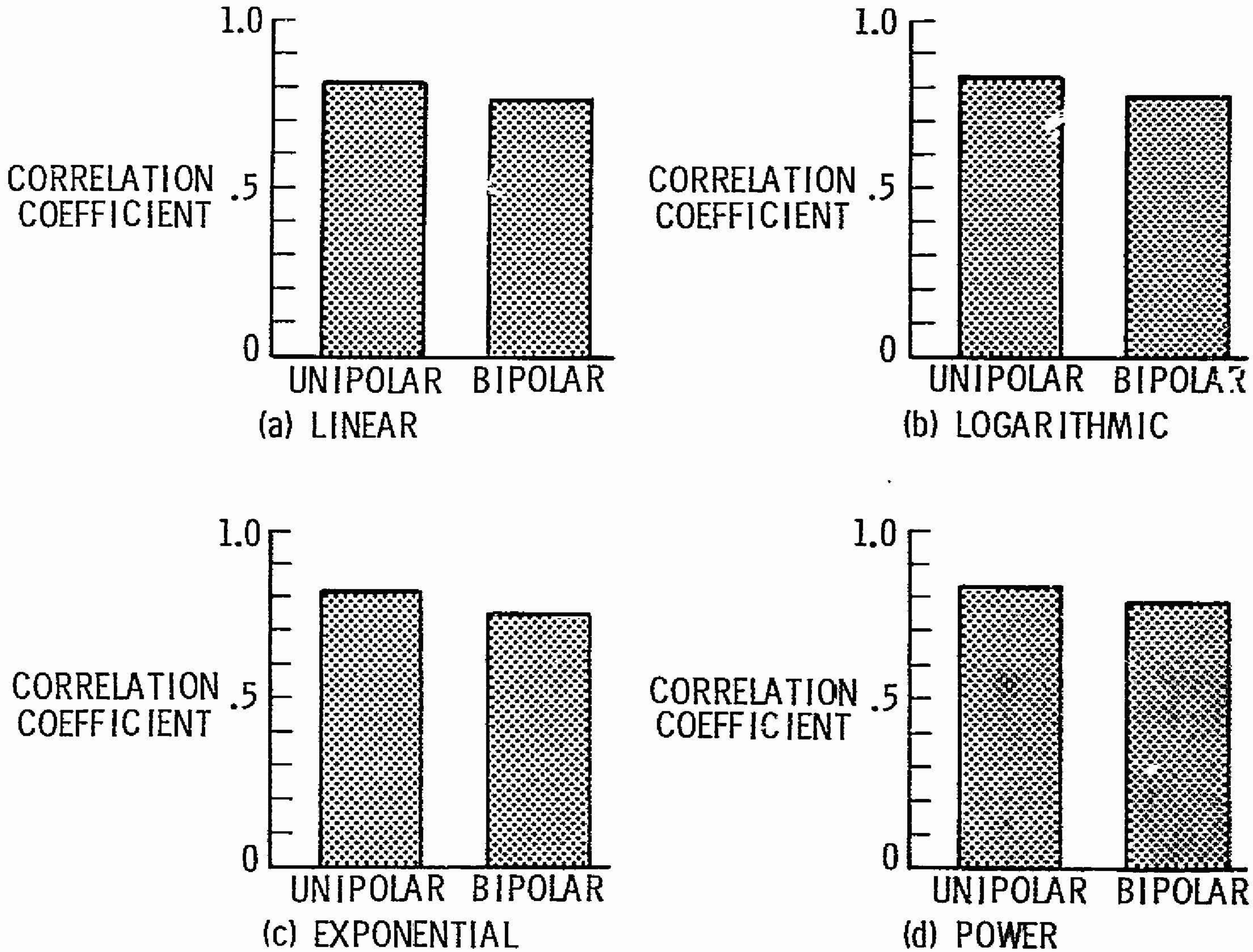
1.0
CORRELATION COEFFICIENT
.5
0
UNIPOLAR
BIPOLAR
(a) LINEAR
(b) LOGARITHMIC
(c) EXPONENTIAL
(d) POWER

Figure 6

Scale type.- Figures 7(a-d) display the correlation coefficients between subjective responses and vibration measures for both continuous and discrete scales for each of the mathematical formulations. The number of data pairs for computation of these correlations and restriction of the degrees of freedom for computation of z-score tests are identical to those for polarity analyses.

There was no statistical difference between the correlations for continuous and discrete type scales for any of the mathematical formulations (z-scores = 0.865, 0.957, 0.999, and 1.066 for linear, logarithmic, exponential, and power comparisons of continuous and discrete scales, respectively). The figures do indicate a trend that continuous type scales allow a greater accuracy of discrimination than discrete scales. In addition, the z-scores for the comparisons were of sufficient magnitude to indicate differences between the scale would occur only 15 to 20 percent of the time. The implication is that the evidence (although not conclusive) suggests that a continuous rather than a discrete type scale should be used for the investigation of subjective reactions to vibration.

Similar to polarity analyses, there were not statistical differences between various psychophysical descriptions. Again, the implication is that selection of the simpler linear relationship is appropriate for description of the psychophysical relationship.

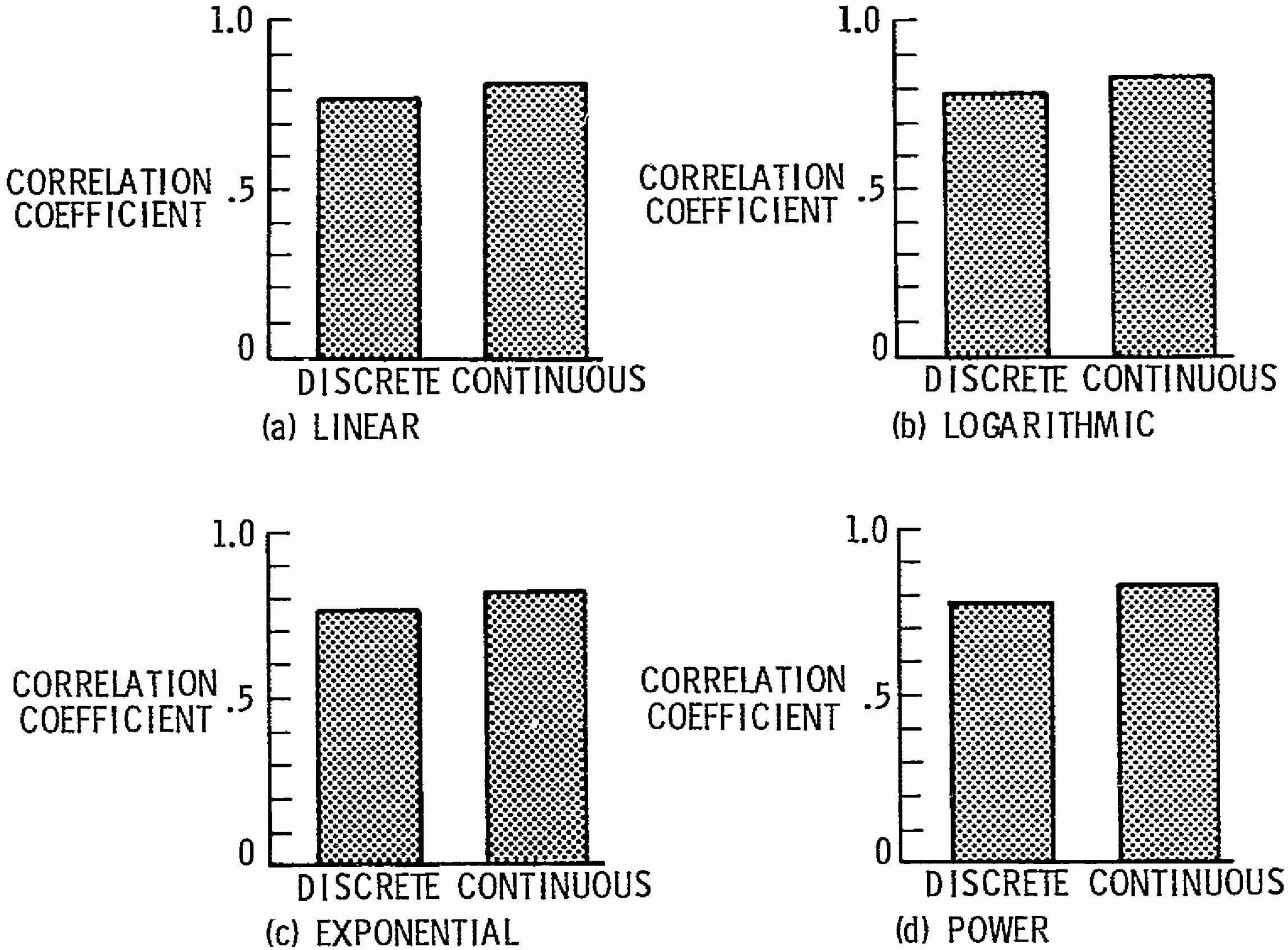
1.0
CORRELATION COEFFICIENT
.5
0
DISCRETE
CONTINUOUS
(a) LINEAR
1.0
CORRELATION COEFFICIENT
.5
0
DISCRETE
CONTINUOUS
(b) LOGARITHMIC
1.0
CORRELATION COEFFICIENT
.5
0
DISCRETE
CONTINUOUS
(c) EXPONENTIAL
1.0
CORRELATION COEFFICIENT
.5
0
DISCRETE
CONTINUOUS
(d) POWER

Figure 7

Scalar points.- Figure 8 (a-d) shows the correlation coefficients between subjective responses and vibration measures for category scales of 3, 5, 7, or 9 scalar points, for each of the mathematical formulations. Information and restrictions regarding the number of data pairs is identical to that for polarity and scale type analyses.

The z-scores obtained from comparison of the discrimination accuracy of these category scales with different numbers of scalar points are displayed in Table IV. These results indicate that the nine-point scale allows a significantly ($P<.05$) greater degree of discrimination accuracy than three-point or five-point (for some comparisons) scales. Analogous to comparisons between scalar points for reliability, these data for discrimination indicate no difference between three- or five-point scales, or between seven- and nine-point scales, but a trend of a higher degree of discrimination accuracy for seven or nine than for three or five-point scales.

Similar to polarity and scale type analyses, there were no statistical differences between mathematical descriptions for any of the category scales varying in number of points. Consequently, several types of analyses imply that the linear law can be selected for description of the psychophysical relationship.

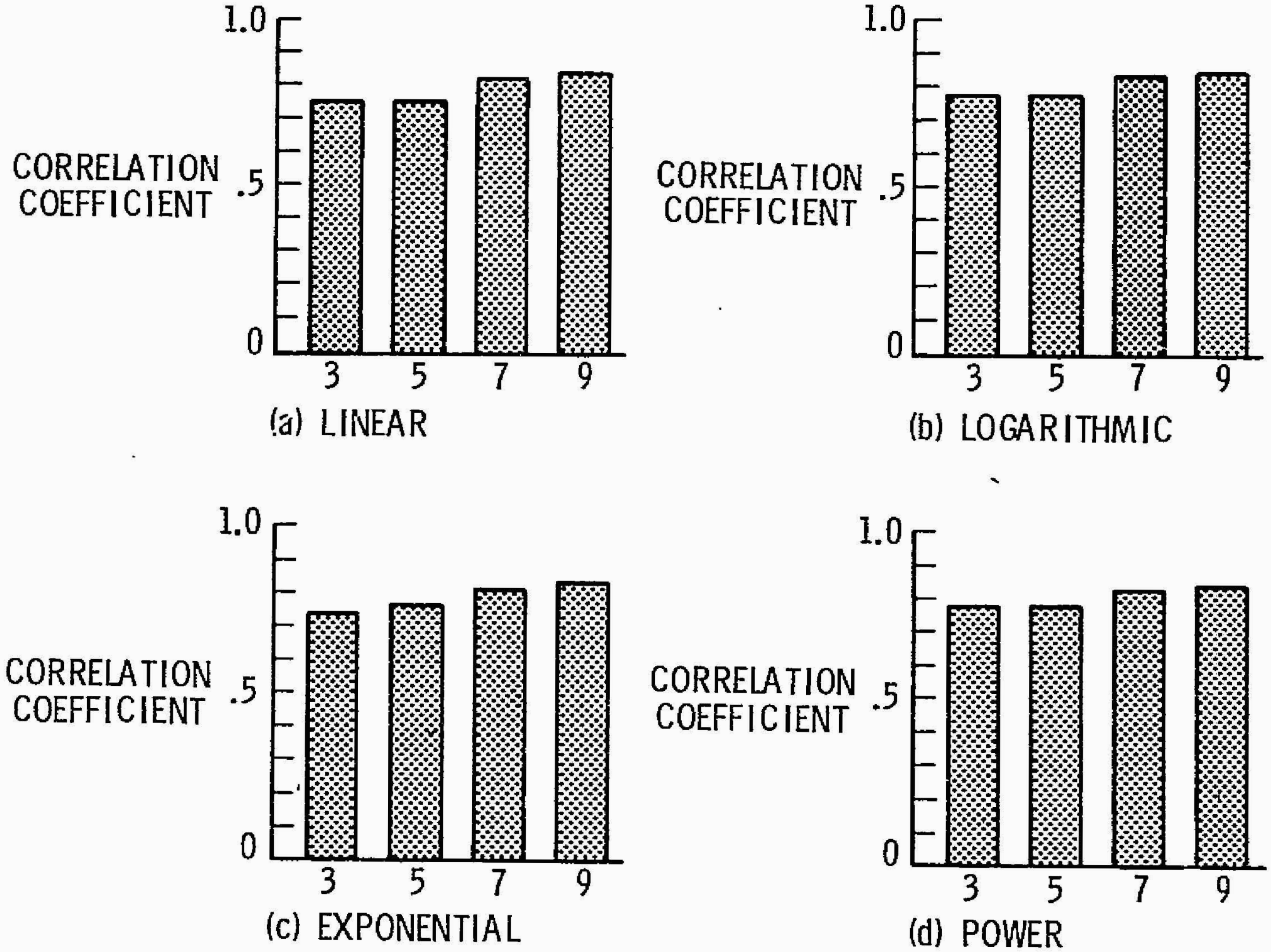
1.0
CORRELATION COEFFICIENT
.5
0
3
5
7
9
(a) LINEAR
(b) LOGARITHMIC
(c) EXPONENTIAL
(d) POWER

Figure 8

TABLE IV.- SUMMARY OF Z-SCORES FROM COMPARISON OF CATEGORY SCALES OF DIFFERING NUMBERS OF SCALAR POINTS

Psychophysical Relationship	Scalar Points Compared					
	3 vs. 5	3 vs. 7	3 vs. 9	5 vs. 7	5 vs. 9	7 vs. 9
Linear	.092	-1.511	-1.763*	-1.419	-1.671	-.252
Logarithmic	.000	-1.545	-1.688*	-1.545	-1.688*	-.143
Exponential	.185	-1.511	-1.763*	-1.327	-1.579	-.252
Power	.109	-1.545	-1.545	-1.436	-1.436	-.000

*$P<.05$; z-score value ≥ 1.64 or ≤ -1.64 needed to achieve statistical significance.

Discriminability summary.- Due to restrictions associated with degrees of freedom, the discriminability analyses were not as conclusive as those for reliability. There were, however, strong trends for discriminability essentially in agreement with those for reliability. Specifically, the category scales that display trends of greater discriminability are of a unipolar continuous nature, with either seven or nine scalar points.

Scale Transformation

The flexibility of a category scale in allowing transformation of the subjective responses to other scales is addressed in this section. Figure 9 shows typical transformation data. The figure displays cross plotting of responses from two different category scales, the responses of which were produced to the same vibration (e.g., frequency by acceleration level). The cross plotted data represents the mean response of 12 different subjects for each of the scales. The correlation coefficient between the responses of the two scales was -.98, and the standard error of estimate (standard deviation about the regression line) was 0.325. This latter value could be considered to represent the accuracy of a particular scale in predicting responses of other scales. Table V displays the mean standard error of estimate obtained for a particular scale when used to predict responses of the other scales investigated. The criterion (predicted scores) were adjusted to a nine-point scale to allow direct comparison between standard errors of estimate. The standard error of estimate numbers were used in Table IV to provide a rank ordering of the category scales in terms of prediction accuracy. These data, as well as similar transformation data indicate: (1) transformation of subjective data between category scales is possible, (2) generally unipolar scales of a higher number of scalar points (seven or nine) allow the greatest accuracy of transformation, and (3) the comfort or positive end of a bipolar scale is not used very often by subjects to describe their sensations.

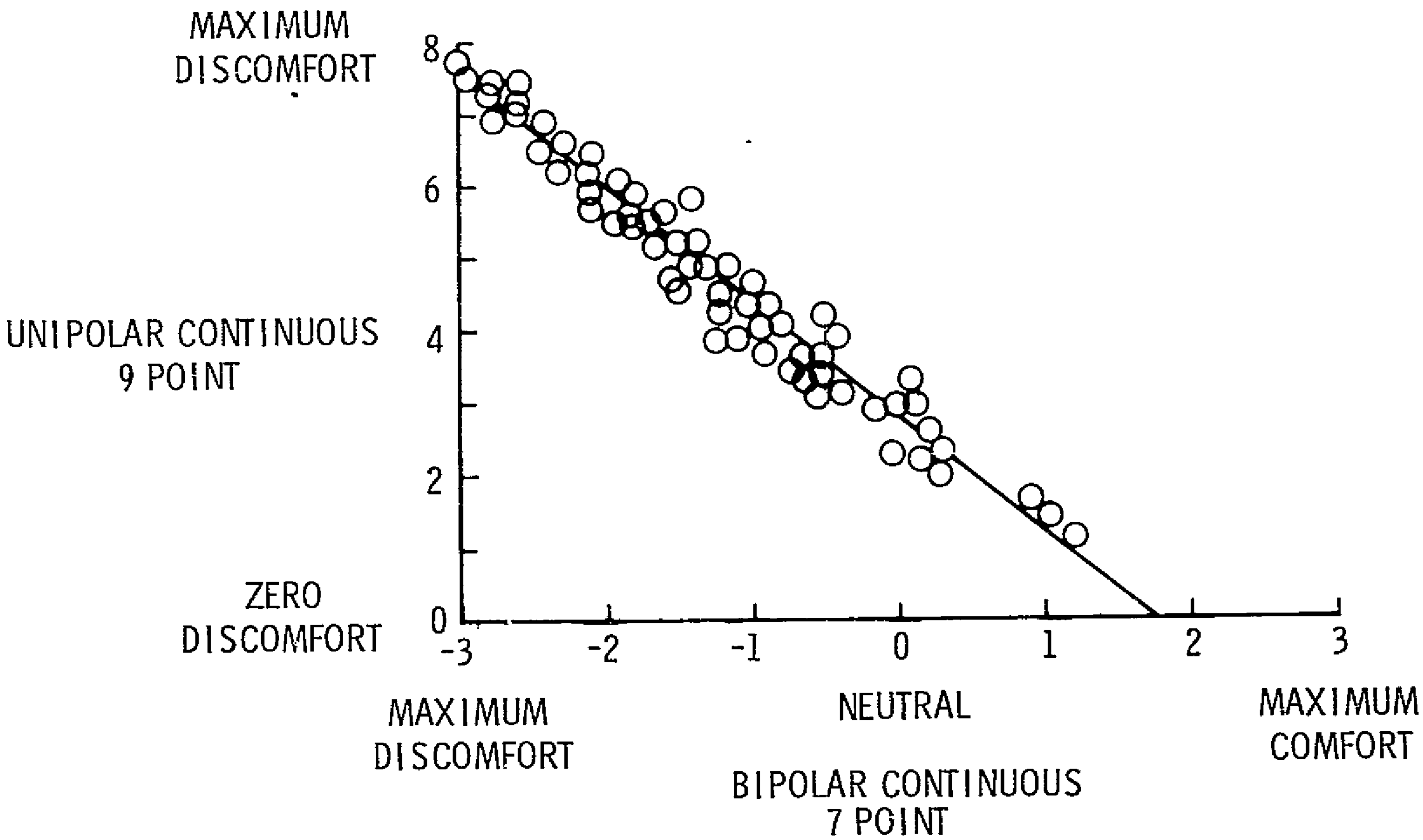
MAXIMUM
DISCOMFORT
UNIPOLAR CONTINUOUS
9 POINT
ZERO
DISCOMFORT
8
6
4
2
0
-3
-2
-1
0
1
2
3
MAXIMUM
DISCOMFORT
NEUTRAL
MAXIMUM
COMFORT
BIPOLAR CONTINUOUS
7 POINT

Figure 9

TABLE V.- A SUMMARY OF THE CATEGORY SCALES RANKED FROM LOWEST TO HIGHEST

IN TERMS OF MEAN STANDARD ERROR OF ESTIMATES

Rank	Scale	Standard Error of Estimate	
1	Unipolar-Continuous	9 points	.425
2	Unipolar-Discrete	7 points	.429
3	Bipolar-Interval	7 points	.451
4	Unipolar-Discrete	9 points	.466
5	Unipolar-Discrete	5 points	.474
6	Unipolar-Continuous	7 points	.474
7	Unipolar-Continuous	3 points	.489
8	Bipolar-Discrete	7 points	.491
9	Unipolar-Discrete	3 points	.498
10	Bipolar-Discrete	9 points	.506
11	Unipolar-Continuous	5 points	.509
12	Bipolar-Discrete	5 points	.522
13	Bipolar-Continuous	9 points	.556
14	Bipolar-Continuous	3 points	.598
15	Bipolar-Continuous	5 points	.662
16	Bipolar-Discrete	3 points	.687

CONCLUDING REMARKS

Several major conclusions regarding category scales that can be derived from this study are: (1) higher degrees of reliability and discriminability are generally obtained for unipolar continuous type scales of either seven or nine scalar points than for other scales, (2) transformation of subjective data between category scales is possible, (3) generally unipolar scales of a higher number of scalar points allow the greatest accuracy of transformation to other scales, and (4) the comfort or positive end of a bipolar scale is not used extensively by subjects for description of their sensations to vibration.

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